Isospin Dependence of Liquid-Gas Phase Transition Properties in Finite Nuclei

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In collisions between nuclei at energies above the Fermi domain, examination of the nuclear caloric curve indicates a liquid-gas phase transition in the finite nuclear system. The phase transition temperature is found to be between 5-7 MeV depending on the colliding systems. The order of the phase transition is, however, still very controversial. Among others, the experimental determination of the transition temperature and the order of the transition becomes complicated, as, depending on the collision geometry, the nuclear material that contributes to the liquid-gas phase transition may be of different sizes and may have different isospin composition. A theoretical analysis of the dependence of the phase transition properties on both the nuclear masses and their neutron-proton ratio is therefore called for in order to have a better understanding of the experimental data.

The nonrelativistic Thomas-Fermi (TF) theory of hot nuclear matter, in broad terms, reproduces the features of the liquid-gas phase transition in infinite matter [1] and also in finite nuclei [2]. The Thomas-Fermi interaction energy density is calculated with the modified Seyler-Blanchard (SBM) interaction. It is momentum and density dependent and is of finite range. It has been extremely successful in explaining very well the ground state properties of a host of nuclei from O^{16} to very heavy systems. The incompressibility of symmetric nuclear matter for this interaction is K = 238 MeV. For hot nuclei, the TF solutions, obtained self-consistently, are dependent on the size of the box in which the calculations are done. For understanding the phase transition properties, we have therefore subjected the nucleus to a 'freeze-out' volume V ~ $8V_0$ where V_0 is the normal volume of the cold nucleus. This is reasonable, fragmentation calculations of nuclei in the statistical framework are usually done with a 'freeze-out' volume which is close to the volume we take.

Each case shows a sharp peak at a temperature T_p around 10 MeV which we interpret as the liquid-gas phase transition temperature. The density profile, which is close to a Woods-Saxon type at very low temperatures evolves to a more or less uniform density [2] at this temperature in the freeze-out volume. We find that this temperature T_p is nearly independent of the mass of the system and also on its isospin composition. Switching off the Coulomb interaction raises the transition temperature by around 1.5 MeV, but the general conclusion about the mass or isospin dependence of the transition temperature remains unchanged.

For infinite nuclear matter, Möller and Serot [3] have shown in the framework of relativistic mean field theory that the liquid-gas phase transition is of first order for symmetric nuclear matter, but the transition becomes continuous for asymmetric systems. Contrary to symmetric matter, the phase transition occurs not at a particular temperature but over a range of temperature for asymmetric nuclear matter. During the transition, the pressure also does not remain constant. For finite nuclei, however, no unequivocal conclusion can be drawn yet. The analysis of the experimental data by the EOS group [4] tentatively points out to a continuous transition, the lattice-gas calculations [5] signal a first-order transition and our preliminary calculations, mostly done for nuclei along the beta-stability line seem to be compatible with the first order transition. For asymmetric nuclei (or even for symmetric systems with Coulomb interaction), the pressure is expected to vary during the phase transition, but numerically the conventional Maxwell construction is found to be an excellent approximation as the differences in the chemical potentials on both ends of the Maxwell line are negligibly small. For very asymmetric nuclei, far away from the beta-stability line, this may not be so and we are presently studying it in more details in both the nonrelativistic and relativistic mean field framework.

References

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